

Natural Hazards Management



Wave-assisted coastal flooding

Rob Bell and **Giovanni Coco** explain some of the factors that go into calculating the risk of coastal flooding in New Zealand.

When storm tide and high waves raise sea levels at the coast, they can cause serious flooding of coastal properties, reserves, and infrastructure. The word serious is used here because storm tides and associated waves can rise quickly to overtop coastal barriers, threatening coastal dwellers, disrupting road or rail traffic, and flooding and eroding valuable coastal real estate and productive farm land.

The effects can linger well beyond the storm event. Erosion of the coastline can, in the short-to-medium term, severely curtail the capacity of a beach to restore itself, leaving it increasingly vulnerable to future storms. And saltwater flooding of productive pasture can render it useless for up to a year.

Understanding the combination of ocean and weather factors that cause coastal flooding will help reduce the risk posed by this hazard. We can reduce exposure to personal injury or damage through timely forecasting of storm-tide events, better prediction methods, and appropriate planning and mitigation measures to ensure real estate and infrastructure are not unduly susceptible.

Large-scale factors causing storm tides

Coastal water levels at the shoreline are the result of different, sometimes unrelated, contributions. These include tides, weather processes, wave set-up in the surf zone, and the individual run-up of waves onto land. Such contributions operate across a range of space and time scales, but can be predicted with varying degrees of certainty. For example, tide levels are accurately forecast and can easily be obtained from tide tables on the web or in newspapers. On the other hand, the effects of winds and a low-pressure weather system on sea levels (storm surge) are difficult to quantify, although they can add up to 1 m to predicted tide levels in extreme situations in New Zealand (and even more in other countries, such as Bangladesh and parts of USA).

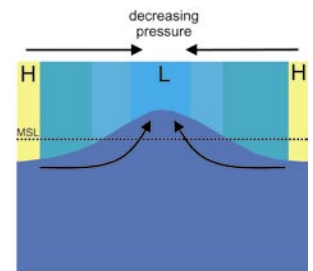
The passage of a low-pressure system, such as a cyclone, is reflected on the sea surface through the inverse-barometer effect, where sea level rises by about 0.1 m for every 10 hPa drop in atmospheric pressure (see diagram).

Winds blowing onshore, or along the coast with the land on its left, can pile up water along the coast. For example, this can happen with southerly winds in Canterbury Bight or northerly winds on the west coast. Wind set-up can be as large as the inverse-barometer effect.

Wave set-down and wave set-up

Short-crested waves approaching the coast undergo a number of changes (shoaling, breaking, and re-forming) that not only affect wave heights but also cause further increases in the mean water level at the coastline. Shoaling waves result in a small depression of the mean water level just offshore of the area where waves break (wave set-down), followed by a more substantial rise of the water level shoreward of wave breaking (wave set-up). Because of wave set-up, the water level landward of the surf zone is not horizontal but becomes steeper until it reaches the beach. As an example, an offshore wave height of 4 m from a sandy beach can produce a wave set-up of the mean waterline by about 0.6 m, certainly a substantial contribution when dealing with coastal inundation hazards!

Predicting wave set-up from the characteristic height of the incoming waves is successful under a limited range of conditions. We also need to account for the way waves



Inverse-barometer effect: mean sea level (MSL) rises in areas of low atmospheric pressure (L) and falls in areas of high pressure (H).

dissipate their energy and break. In general, wave set-up is larger over steep seabed slopes and large wave conditions. Recent research conducted on Australian and American coasts seems to indicate that other variables (such as tide level and surf-zone sandbars) must be included to predict wave set-up accurately.

Wave run-up

Individual waves progress much farther up the beach slope beyond the mean waterline already increased from wave set-up. The so-called swash zone is the part of the beach slope (or adjoining land) which is progressively covered by water while flow runs up, and then uncovered while flow runs down. The swash zone is more visibly subject to intense erosion and overtopping during storm conditions, particularly during a high storm-tide when the foredune or beach barrier becomes much more accessible to attacking waves. For this reason, research has focused on understanding the link between rapid flows, tides, and sediment movement in the swash zone, and on developing techniques to make these measurements in such a hostile environment. These studies have established the role of wave set-up in determining the position of the increased mean waterline, and then have focused on understanding the highly variable oscillations from individual wave run-up relative to that mean waterline.

Historically, coastal hazards have been assessed using a wave run-up elevation exceeded by 2% of the individual waves, based on relationships between the offshore waves and the slope of the beach (or the seawall structure). Recent advances have indicated the relevance of longer waves with a period of 20–240 seconds for the prediction of run-up elevations. However, a universal formula for wave run-up is elusive and other processes potentially affect run-up elevations. These processes are related, for example, to infiltration, sediment grain size, and waves approaching the shoreline at an angle.

Applying coastal flood predictors

Predictions of storm-tide, wave set-up, wave run-up, and sea-level rise (and also tsunami) on New Zealand coasts are all important in assessing the susceptibility of coastal property to wave-induced overtopping, inundation, and erosion. Understanding the processes governing wave set-up and wave run-up on different New Zealand beaches also helps us to design measures for coastal-hazard mitigation and, ultimately, increases our understanding of beach behaviour.

Further reading

Bell, R.G.; Gorman, R.M. (2003). Coastal hazards. *Tephra* 20 (June): 21–26. Available online at www.mcdem.govt.nz/ under *Tephra*.


de Lange, W.P. (2003). Tsunami and storm-surge hazard in New Zealand. In: Goff, J.R.; Nichol, S.L.; Rouse, H.L. (eds). *The New Zealand Coast: Te Tai O Aotearoa*, pp. 79–95. Dunmore Press, Palmerston North, with Whitireia Publishing and Daphne Brasell Associates Ltd.



Photo: Doug Ramsay

Wave run-up at Otamarakau.

New Zealand's variety of coastal morphology and wide range of tide and wave conditions limits the usefulness of many of the empirical formulae presently available. Also, we cannot simply add together the worst-case situations for each process that contributes to potential flooding of low-lying coastal margins (for example, high tide + storm surge + wave effects + sea-level rise). Such a combined event would have a very low probability, leading to an overly conservative approach. Designing for tsunami is a separate consideration.

NIWA's research on coastal inundation hazards focuses both on large-scale factors (storm-tides, sea-level rise) and smaller-scale wave set-up and run-up processes. We coordinate a network of 21 sea-level gauges along the open coast which can provide warning of a pending high storm-tide. We also publish Red-Alert Dates each year for days when very high tides will occur and potentially could lead to coastal flooding if there is a coastal storm at the same time. NIWA plans to run swash-zone experiments at coastal sites with diverse wave climate and beach conditions to determine which variables control wave set-up and run-up. The ultimate goal of such investigations will be to provide New Zealand-specific formulations and guidance that can reduce the risk of coastal flooding through more informed land-use planning and engineering design of coastal protection works and infrastructure such as coastal roads. 

Dr Rob Bell and Dr Giovanni Coco both work at NIWA in Hamilton. Rob leads NIWA's research in coastal and maritime natural hazards and Giovanni specialises in nearshore and shoreline coastal morphodynamics.

Useful links

New Zealand tides:
www.niwa.co.nz/services/tides/

Red-Alert Dates for New Zealand coasts and NZ sea-level network:
www.niwa.co.nz/services/sealevels